CONSTRUCTION OF A 10-HP. HEAVY DUTY GAS ENGINE

BY

M. D. GOTTLIEB
G. M. HENRY
JACOB MITNICK

ARMOUR INSTITUTE OF TECHNOLOGY

1920

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CONSTRUCTION AND RE-DESIGN OF A 10-HP. HEAVY DUTY GAS ENGINE

A THESIS

PRESENTED BY

MARSHALL D. GOTTLIEB GEORGE M. HENRY
JACOB MITNICK

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

MAY 27, 1920

APPROVED:

Geo. F. Gebhardt
Professor of Mechanical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

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CONSTRUCTION OF 10 H. P. GAS ENGINE.

FOREWORD

In the presentation of this thesis, the writers have endeavored to take up the work of a former thesis, entitled "The Design-Study of a 10 H. P. Gas Engine", by A. J. Plocinsky and C. R. Pomeroy, in constructing their original engine, and carrying out a redesign as necessary for best results in the final engine.

The writers wish to express their appreciation of the kind assistance of Professor Daniel Roesch.

M. D. G.

G. M. H.

J. J. M.

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The Construction and Redesign
Of A 10 H. P. Heavy Duty Gas Engine.

By

M. D. Gottlieb

J. J. Mitnick

Geo. M. Henry

OBJECT

This work was taken up by the author as a Progress Thesis.

In 1917, Messrs. A. J. Plocinsky and C. H. Pomeroy designed a heavy duty single cylinder gasoline engine with new ideas involved. Their object was primarily to bring out an experimental engine to be used in the laboratories of the Armour Institute of Technology. Provisions were made in their original design whereby such changes as valor timing, cam designing and compression could be easily brought about.

Their layout included a "valve in head" feature, in which two smaller exhaust valves and one larger inlet valve were utilized. The theory

advanced for this construction was that, inasmuch as the exhaust valves were exposed constantly to the hot gases leaving the cylinder, a reduction of valve size would prevent warping of the valve due to excessive heat.

The cylinder head was designed with a spherical combustion head, and the valves arranged at an angle of 45° to the center line of the cylinder.

Other than the cylinder head and valve gear, the remainder of the design seems to follow conventional practice. All machine parts were designed upon empirical and rational formulae of strength of materials. They were then altered to suit the special conditions.

Their work consisted only of the design of the original engine. The construction and redesign was left for future theses at the Institute, and it was this work that was taken up by the authors of the writing herein carried out.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

In the original thesis a conclusion was inserted, which provided a rough outline for future progressive work based on the first design.

The Conclusion.

I. Valve Gear.

The part of the valve gear attached directly to the cylinder head is somewhat bulky; and with further study and experiment it could probably be simplified and perfected.

2. Flywheel and Crank Shaft.

The rational design and theoretical analysis of the flywheel and crank shaft were beyond the scope of the present work. These would form an important part of the work of the further study and design of this engine. Included in this study will be the various inertia and shaking force diagrams to show the necessary balancing required.

3. Bearings.

A study of the bearings required and a determination of the most suitable type for each location must be made.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

4. Lubrication.

Pressure lubrication with continuous circulation has been decided upon. The best means of lubricating the crank pin and piston pin must be considered.

5. Governing.

The governing mechanism will be studied and designed more in detail.

6. Ignition.

Magneto ignition has been decided upon, but the method of spark control will be taken up.

7. Carburetion.

Carburetion will have to be studied in conjunction with governing. It is recommended that the Stewart vacum feed system be considered. A tank can be placed at the bottom of the frame.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

Comments on the Conclusion of the Original Thesis.

1. The Valve Gear.

An attempt has been made in this work to redesign the valve gear, and eliminate certain constructive features of the original design.

2. Flywheel and Crank Shaft.

A complete investigation and layout of the inertia and shaking forces has been made.

3. Bearings.

As will be noted in the chapter on "First Elements of Redesign", we have analyzed and decided upon the proper design of the various bearings.

4. Lubrication.

To bring under a thorough study the question of lubrication, a special chapter on lubrication, carburetion, ignition and cooling has been inserted.

5. Governing.

No attempt will be made to study the governor design in the present work. This will be left for future investigation.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

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CONSTRUCTION OF 10 H. P. GAS ENGINE.

CHAPTER ONE.

The following parts have been completely machined in the Institute shops up to date.

1. Cylinder.
2. Cylinder Head.
3. Piston and Rings.
4. Connecting Rod.
5. Crank Shaft.
6. Crank Shaft Bushings.
7. Valves.
8. Valve Cams and Levers.
9. Valve Operating Mechanism.

The engine base was not machined at the Institute, because of the fact that it was too large to be finished in the horizontal boring mill. It was sent out for machining and was returned completely finished. The flywheels are to be purchased and then bored to fit the 3¼" crank shaft.

The carburetor and magneto were obtained from standard stock at the gasoline laboratory.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

The first job undertaken was that of a cylinder. This is quite a heavy casting and required the largest lathe in the shop.

The end facing on the base flange was machined first. To do this, the casting was clamped at the head end in a large universal chuck with jaws reversed. For a reason stated later, the cylinder flange was not turned strictly face-true but was tapered a certain amount.

After the flange was turned up, the cylinder was reversed and chucked at the head end. The job was now ready for rough boring. This was done by a rigid post-tool extension, having an inserted tool of high speed steel. The finish boring cut was next taken and the cylinder was ready for finished grinding. This was done by means of a universal lathe grinder and tolerance was held to .001" on this job. This completed the boring work on the cylinder.

It was again reversed and faced at the head end, and all important operations were completed.

After the engine base was completed in an outside machine shop, the cylinder was clamped

to it in position with a T-bolt. The cylinder base holes were then scribed and spotted. The casting was then removed and each scribed hole was accurately centered. They were then drilled 41/64" and tapped by hand to 3/4" standard U. S.

The water jacket, inlet and outlets, were drilled and tapped for a 3/4" pipe.

The only work then remaining, was drilling and tapping for the cylinder head studs. This was not done until the cylinder head was completed, for the reason that it was used in spotting the stud holes.

Operations on the Cylinder.

1. Face Flange End.
2. Rough Bore.
3. Finish Bore.
4. Finish Grind.
5. Face Head End.
6. Drill and Tap Base Holes.
7. Drill and Tap Water Holes.
8. Drill and Tap Head Stud Holes.

The piston was next taken up. The first operation on the piston consisted of chucking and rough turning in a geared-head, Reed and Prentiss lathe. Finished turning was next performed and held to close limits. Hand filing brought out the desired finish. The piston on this engine is slightly tapered and so the lathe carriage was set to provide for this. Grooving was next performed. This was done in the conventional manner with a special grooving tool on the same machine. A special groove gauge was used for both width and depth. The piston skirt was then slightly faced to finish up that end,

The piston pin bosses were then taken up. They were rough drilled on a large drill press with the piston clamped in -V- blocks. Following drilling, they were reamed to finish size.

The holes in the bosses for the wrist pin set screws, were drilled and tapped on the same machine.

The final operation on the piston consisted of sawing off the false boss on the piston head.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

Operations on Piston.

1. Rough Turn.
2. Finish Turn.
3. Face.
4. Groove.
5. Drill and Ream Piston Bosses.
6. Drill and Tap Set Screw Holes.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

The piston rings were then taken up. The casting from which the rings were made was cast in a single shell, with a heavy end for chucking.

The first operation was outside turning, both rough and finish. Then came inside boring, also rought and finish. After this was done, the rings were cut from the shell with a lathe cut-off tool. They were then dressed on the sides to fit the particular groove in the piston to which they were assigned. After dressing, the rings were split with a 45° cut and hand filed to fit the cylinder bore accurately. One leak-proof ring was used in the second groove from the top.

Operations on the Piston Rings.

1. Turn Shell (Rough)
2. Turn Shell (Finish)
3. Bore Shell (Rough)
4. Bore Shell (Finish)
5. Dress Sides.
6. Split and Fit Bore.

CONSTRUCTION OF 10 H.P. GAS ENGINE.

The connecting rod was the next job to be undertaken. The first operation consisted of centering and gauging. By means of the surface gauge and calipers the working center was determined; and with the use of false wooden centers, the longitudinal center line was scribed. This determined the center of the rod at each end, and center holes were drilled at these points to aid in subsequent operations. Facing of both ends was next undertaken on the large planer. The piece was rigidly clamped with T-bars to the bed of the planer. Two roughing cuts and one finishing cut were taken of both ends, and then the operation repeated on the other side. The bolt holes at the lower end were next taken up. The rod was clamped in an inverted vertical position by means of angle plates, and rough drilled, and then followed by finished reaming. While this set-up was maintained, the holes were counterbored for the bolt heads. The next operation consisted of finishing the opposite face of the bolt holes. This was done on the shop shaper, in one setting. The horizontal boring machine

was then set up for the machining of the holes at both ends. With false wooden centers again in place, circles were scribed at both ends, to indicate the final cut to be taken. The rod was then set up and clamped with angle plates, and rough cuts taken until the hole was brought out to size at each end. The final operation on the rod proper consisted of saw milling or splitting the lower half of the rod in a large milling machine.

Operations on the Connecting Rod.

1. Gauging and centering.
2. Facing Both Ends.
3. Drilling of Bolt Holes.
4. Counterbore Bolt Holes.
5. Finish Bolt Hole Face.
6. Rough and Finish Hole-Large End.
7. Rough and Finish Hole-Small End.
8. Split Large End.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

The crank shaft was the next part to be machined. The first operation was rough turning of the bearing shafts on a standard engine lathe. In order to machine the crank pin, special end carriers were designed and made up, and pressed onto the ends of the shaft. They were then carefully lined up, and the whole placed in the large lathe. The crank pin was then rough turned and finished. The polishing was done with a special emery holder. After the crank pin was completely finished, the bearing shafts were finish turned and polished. Gauging was done by means of special snap gauges made in the machine shop.

Operations on Crank Shaft.

1. Rough Turn Bearing Shaft.
2. Rough Turn Crank Pin.
3. Finish Turn Crank Pin.
4. Finish Turn Bearing Shaft.

The crank shaft bushings were next taken up. The first operation consisted of rough boring, on an engine lathe. Rough facing also took place at this set-up. Holes were then drilled through the bushing for the anchoring of the babbit lining; and a special jig was constructed for this operation. After the babbitting was done the bearing was bored out to size and then outside turned and faced to fit the bearing cap. In the original design, the drawings called for the splitting of the bushings so that adjustment could be provided by means of shims. It was decided, however, to leave them solid, and split them later on when bearing adjustment should become necessary.

Operations on the Bushings.

1. Rough Bore and Face.
2. Babbit.
3. Finish Bore.
4. Finish Turn.
5. Finish Face.
6. Cut Oil Grooves.
7. Drill and Tap for Grease Cup.

The cylinder head was the next part to be machined. The first operation consisted of rough and finish planing on the large Gray planer. This, then, gave a finished surface from which to gauge the machining of subsequent operations. The next operation was the turning of the mating or split surface on the large lathe. Here the outer ring was first rough and finish turned. The inner ring is tapered with a conical portion that snugly fits a mating surface in the cylinder, itself. Care was therefore taken at this point in the procedure, to accomplish the desired results. Many trials were necessary before the fit was as desired.

The next operation consisted of the drilling, counterboring and tapping of the spark plug hole. As the casting came from the foundry, it embodied no depression for the spark plug machining operations. It was therefore necessary to first lay out, carefully, the center of the hole. A 1/2" hole was then drilled straight through the entire casting. Following this, came the counterboring to accomodate the body of the plug itself, and allow for its manipulation with a standard socket wrench. A 3/4" hole was then drilled, using

the previous hole as a center; this larger size providing for the 7/8 - 18 tap.

The next operation consisted of planing the flanges on both inlet and exhaust ports. This was accomplished in a manner similar to that in which the top of the head was first planed. Following this, the bolt holes for the flanges were drilled and tapped.

The final operation consisted of drilling, reaming, boring and facing of the valve stem guides and seats. For this operation a special jig was designed, using the top of the cylinder as a guide and holding the same at angle of 45° to the vertical. First the three valve guides were drilled, care being taken to see that the drill located itself accurately. The holes were then finish reamed to size. The valve seats were roughed with a 45° boring tool and finally reamed out accurately. When the valves were inserted later on, they were ground to the seats with a special valve-grinding compound.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

Operations on the Cylinder Head.

1. Rough and Finish Plane Top.
2. Rough and Finish Turn Mate Surface.
3. Locate, Drill and Counterbore Spark Plug Hole.
4. Plane Flanges on Valve Ports.
5. Drill and Ream Valve Guides.
6. Bore and Ream Valve Seats.
7. Drill and Tap Top for Valve Gear Support.
8. Drill Cylinder Head Bolt Holes.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

The valves were next machined. As they were received, they were practically finished all over; and so the only operations necessary were grinding to the seat, and drilling the ends for spring retaining seats.

The cams were rough turned and faced, and then finish ground after profile filing. The hubs were then drilled and tapped for set screws.

The cam shafts rocker arms and adjusting pins were machined in the conventional manner, care being taken to see that the proper alignment of the entire mechanism was accomplished.

The valve operating mechanism consists of the lay shaft, which is carried parallel to the cylinder; and the operating sets of bevel gears at both ends. The shaft is carried in bronze bearings, supported from the engine base at three points. The bevel gears were purchased completely machined. The other parts were built in the machine shop.

CHAPTER TWO

Difficulties Arising in Redesign and the Machining of Parts.

When the engine base was cast in the foundry at the Institute, it was found by inspection that it was altogether too high to be placed on the horizontal boring mill available. Therefore the only solution of the problem lay in the machining of this part in some outside shop. And so no work was done on the base at the local shop. In the redesign, however, this base was cut down 8", so that it could easily be machined in the horizontal boring mill.

In the original thesis, the reason forwarded for the high design of the base was to leave enough distance for the fly wheels to clear the floor. But in the actual set-up the base is laid on a foundation of concrete which in itself is high enough to take care of the decrease in size of the base.

In the design of the bearing caps, no provision was made by the drawings for overhang

and shimming. Provision, however, was made for this in the redesign, as indicated by the assembly plate contained in this work.

The connecting rod in the original design had a provision for changing its overall length by means of shimming at the crank pin end. It was deemed advisable, however, in redesigning the rod to eliminate this adjustment on the connecting rod and use a standard marine or automobile type of rod having a pressed bronze bushing inserted at the wrist pin end and a split bronze-backed babbit bearing at the crank pin end. The adjustment provided to vary the compression was placed between the cylinder and the engine base. A slip spline is provided in the valve gear driving or lay shaft to provide for this change of overall length of the engine, upon which the valve operating mechanism is placed.

In the original design of the valve gear, considerable overhang was present, due to a lack of compactness of design. The distance from the end face of the cylinder head to the outermost portion of the valve arms was 12". This was reduced in the

redesign to 7" by using bent rocker arms instead of the conventional straight arms. This necessitated a change in the leverage, and also the cams; because of the fact that a "one to one" lever arm was now used instead of the "one to two". This, then, required a cam whose lift was twice that of the original cam, and whose base circle was also twice the size of the previous. This was necessary so that the essential proportion of the cam contour be maintained in order to retain the original cam characteristics.

The re-arrangement of the valve gear also allowed for a 5" reduction in the length of the lay shaft.

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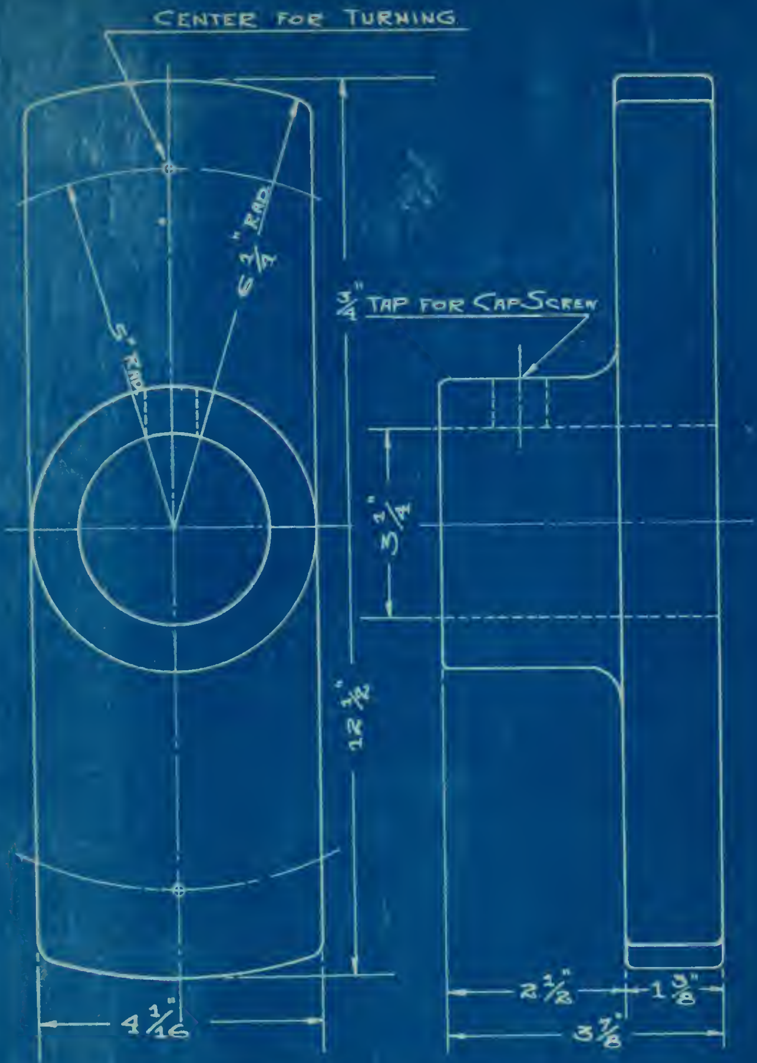
CHAPTER THREE

Special Jigs and Fixtures Used.

In the building of this engine, as well as in the production of most any machine of complication, numerous special jigs, fixtures and set ups were employed. Some of the more important ones are described herewith.

In the turning of the crank shaft, two offset center pieces were required. These were necessary in the turning of the crank pin, which has a throw of 5". This necessitated two offset pieces having a center distance of 5". They were made of cast iron, very heavy; especially so, near the hub where they were pressed onto the crank shaft.

Their construction is clearly illustrated in the drawing. For safety and also convenience, they were made with two centers 180° apart as shown. In the fitting, the crank shaft was first rough turned and filed at each end for a distance of about 7". Then it was carefully measured with the micrometer calipers and the hole in the hub of the jig,



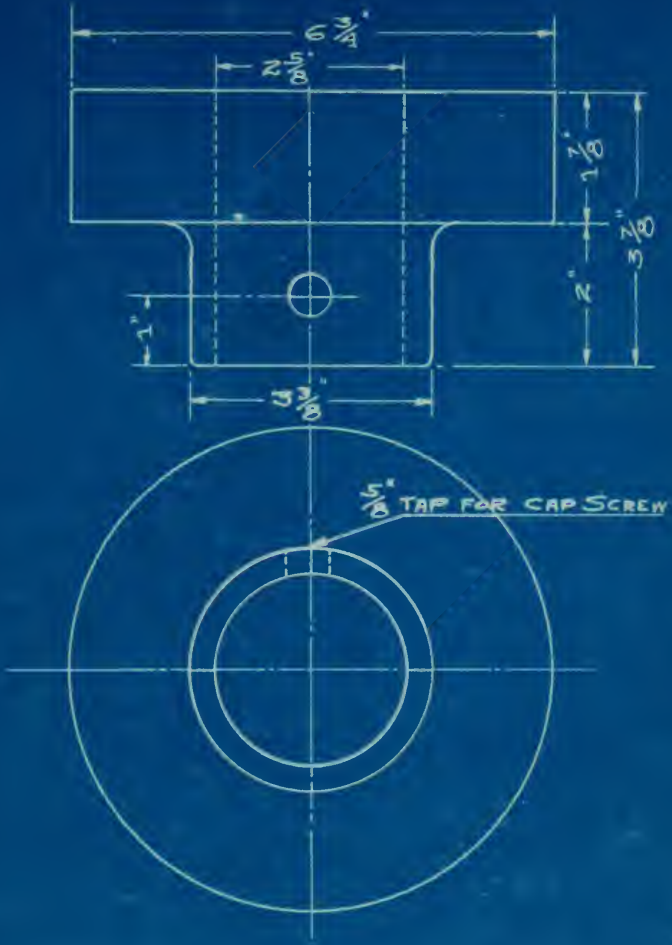
JIG FOR TURNING UP CRANK SHAFT

NO. WANTED - 2.   MAT. - C.I.

bored out .005" undersize. These were then pressed on and carefully fitted.

In the turning of the cylinder ends or flanges, a special arbor carrier was made as shown in the cut. This consisted of a 2½ inch arbor, upon which were keyed two cylindrical carriers, turned up accurately to fit the cylinder bore. In order to drive the cylinder, one of the carriers had set screws at its outer periphery, that could be made to bear against the bore of the cylinder, and so carry it around positively.

In the fitting of the studs to the cylinder base flange, they were turned up a little oversize on the threads; and some means had to be used for forcing them down to the required depth. This was accomplished by means of a special stud driver which is herewith illustrated. The main body is tapped to fit the threaded part of the stud somewhat loosely, and this is screwed down a certain distance on the stud. The small set screw is then tightened and the body of the driver, which is hexagonal, is then turned with a large wrench. This carries the stud down the required



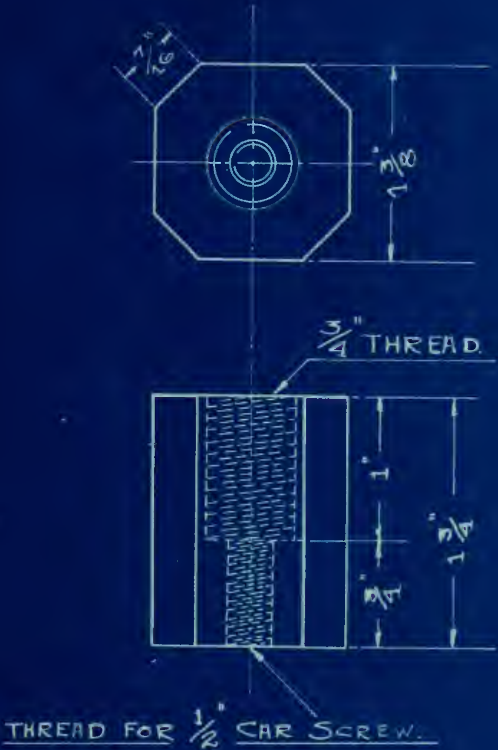
ARBOR: USED TO TURN UP CYLINDER

NO. WANTED - 2. MAT: - C. I.

distance; and by loosening up the set screw, the driver is easily screwed off the stud.

Special gauges were made up for use in the turning of the crankshaft and crank pin. These were all carefully hardened.

In the boring of the ends of the connecting rod on the horizontal boring machine, special brackets and angle plates were made up as incidental in the machining.



STUD DRIVER
MAT: TOOL STEEL.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

CHAPTER FOUR

First Elements of Redesign.

Part One

A New Valve Gear.

In the original design, the layout of the valve gear was made primarily with the idea of large valve travel as compared to the rise of the cam producing it. The result was that a very unwieldy valve gear was laid out, which had bad features of overhang. This was due to the use of "one" to "two" rocker arms. That is, the cam action or rise was only one-half that of the valves.

In the redesign, the object was to obtain compactness of design and disregard for the time the relation between the valve travel and cam lift. The first change necessary was in the bending of the valve rocker arms to resemble bell cranks so as to bring the cam shaft closer to the cylinder head, and render the design more compact. This allowed for best results the use of a "one" to "one" valve

operating arm, resembling a bell crank quite closely.

In order to obtain then, the same lift of the valves with the changed arm, it was necessary to alter the design of the valve cams. The lift of the valves as determined originally, was 1/2". The original cams had a maximum rise of 1/4". The cams now had to be increased in size and base so as to accomodate a 1/2" rise; because of the "one" to "one" arm arrangement.

The assumption was made, that for best all around experimentation, it would be best to design the cams with constant acceleration rise, and constant retardation drop.

As seen from the layout on the drafting table, it was best to take the base circle of the cam at about two inches in diameter. That is, four times the lift. According to conventional practice, the following valve timing data was decided upon for initial design and experimentation.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

Inlet Opens --- 12° after head end dead center.

Inlet Closes -- 35° after crank end dead center.

Exhaust Opens - 40° before crank end dead center.

Exhaust Closes- 10° after head end dead center.

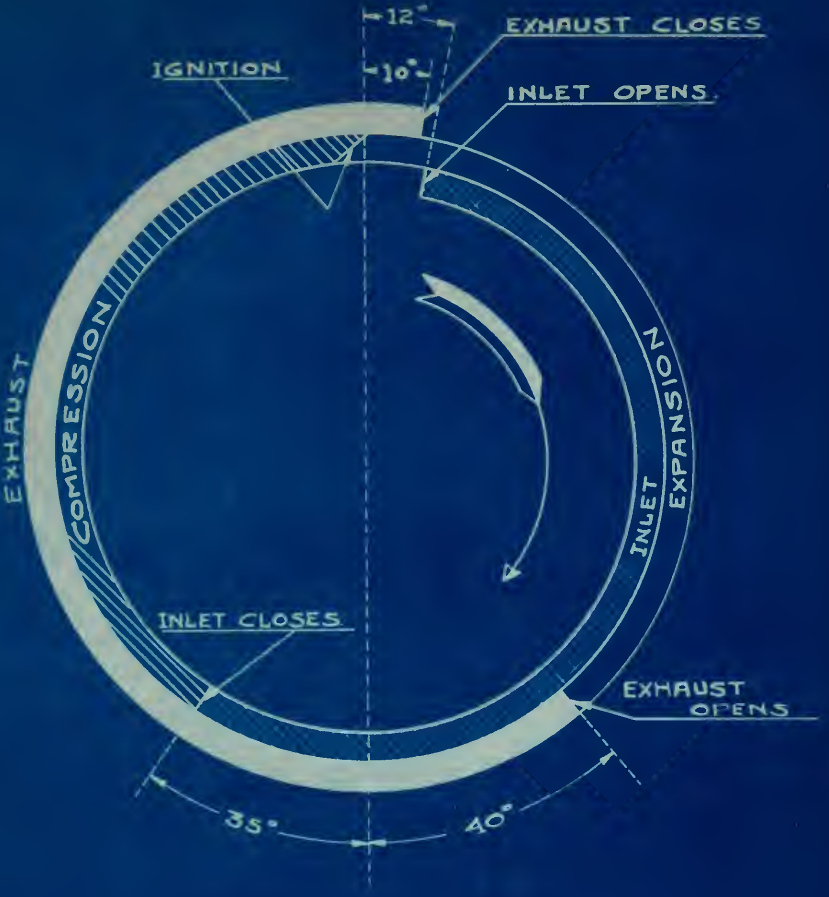
The valve timing diagram is shown.

This assumed data required different cams for exhaust and inlet valves, since the inlet valve is open for 35°+180°-12°= 203° of crank travel.

The exhaust valve is open for 40°+180°+10° = 230° of crank travel.

Inasmuch as the cams revolve at 1/2 the speed of the crank shaft, the action in degrees of the inlet valve cam is equal to 203/2 = 101.5°; while the action in the exhaust cam is 230/2 = 115°.

The base circle was then laid out as 2" in diameter for each cam. The angle "Θ" for the action of each cam, was laid out and this angle bisected. This gives the line on which the maximum rise is to occur, and the rise is



VALVE TIMING DIAGRAM

laid off at 1/2". Using the center of the base circle, and with a radius equal to 2½", the dwell arc was scribed. The angular magnitude of this was assumed at 15° of crank travel or 7½° of cam action. The cam contour between the dwell ark and the limits of action on each side, were designed to give a motion of constant acceleration to the cam rise and constant deceleration to the fall. This gave a symmetrical cam profile which is very much desired in practice.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

Part Two.

The Cylinder Head.

The cylinder head did not suffer many changes in redesign, but some minor changes were made in its layout to render it easier to machine; and also to better the actual performance of the engine.

The first change that was made was the elimination of the conical ridge and seat at the joint between the cylinder head the cylinder proper. This was done because of the difficulty in producing a simultaneously tight joint on both the surfaces involved. Also the difficulties in making a copper gasket were also decreased. It is true that with this previous construction of the joint, perfect alignment of both parts is easily obtained; but if care is taken in the machining of the cylinder head studs and stud holes, the desired accuracy can be just as easily obtained.

The other change consisted of altering the valve seat angle so that it was now 45° instead

of 60° as formerly. This was done in order to follow standard practice, and allow the installation of standard purchased valves.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

Part Three.

Reduction in Height of Engine Base.

The engine base was reduced in height approximately 7½" in order to allow for its machining on the horizontal boring machine. In the first design this was made high enough to accomodate the flywheels chosen. Provision was made however, to give clearance to the flywheel by making the concrete foundation high enough to provide the same.

The other important change was that of the main bearing caps. These were redesigned to provide for the wear take-up by means of shims which can be taken out on each side of the journal when the necessity for adjustments arise. The bearings are also provided with a step split, which prevents any misalignment cause by abnormal stresses.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

Part Four.

Changes in Reciprocating Parts.

Several changes were made in the piston, connecting rod and wrist pin, which in no way affect the principal design or operation of the engine. One change, however, due to constructional reasons, limits the adaptation of this engine toward the variation of compression, by changing the length of the connecting rod. In the original design, the large end of the rod was made so that shims could be placed between the brasses and rod proper, in order that the center to center distance between the wrist pin and crank pin could be varied, and so change the compression. In the redesign this was altered, because of the availability of drop forgings, which were designed along the style of the automobile type.

The wrist pin end has a pressed bronze bushing inserted in the bored hole. The crank pin end is split, and has a bronze-backed babbit bearing inserted.

The wrist pin is made hollow and con-

tains ducts for the circulation of oil to the wrist pin bearing.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

Part Five.

A Built Up Crank Shaft.

In the machining of the original one-piece crank shaft, considerable difficulty was encountered in the turning of the crank pin. Also the forgings obtainable did not allow of a size as large as was desired.

In order to simplify machining operations, and for strength considerations also, a built-up crank shaft was designed. This eliminated, first, the need for eccentric jigs with which to turn the crank pin; and, second, the need of procuring a forging. All parts could be made up of standard machine shop stock, since the bearing shafts and crank pin were straight stock; and the crank cheeks were designed to be made of standard flat steel. The crank pin and shafts were first to be turned and made .005" oversize as compared to the hole in the crank cheek, in order to provide for a shrink fit.

Round keyholes were drilled and keys inserted, to help take up the torsional strains at the joint between the cheeks and the shafts.

CHAPTER FIVE.

The Investigation of the Shaking Forces.

In the determination and layout of any system of unbalanced forces it is first necessary to assume a tentative indicator diagram, from which the thrust on the piston is obtained.

The data assumed was as follows:

Suction Line --- 1½ lbs. below atmospheric.

Compression Line --- $pv^{1.3} = C$.

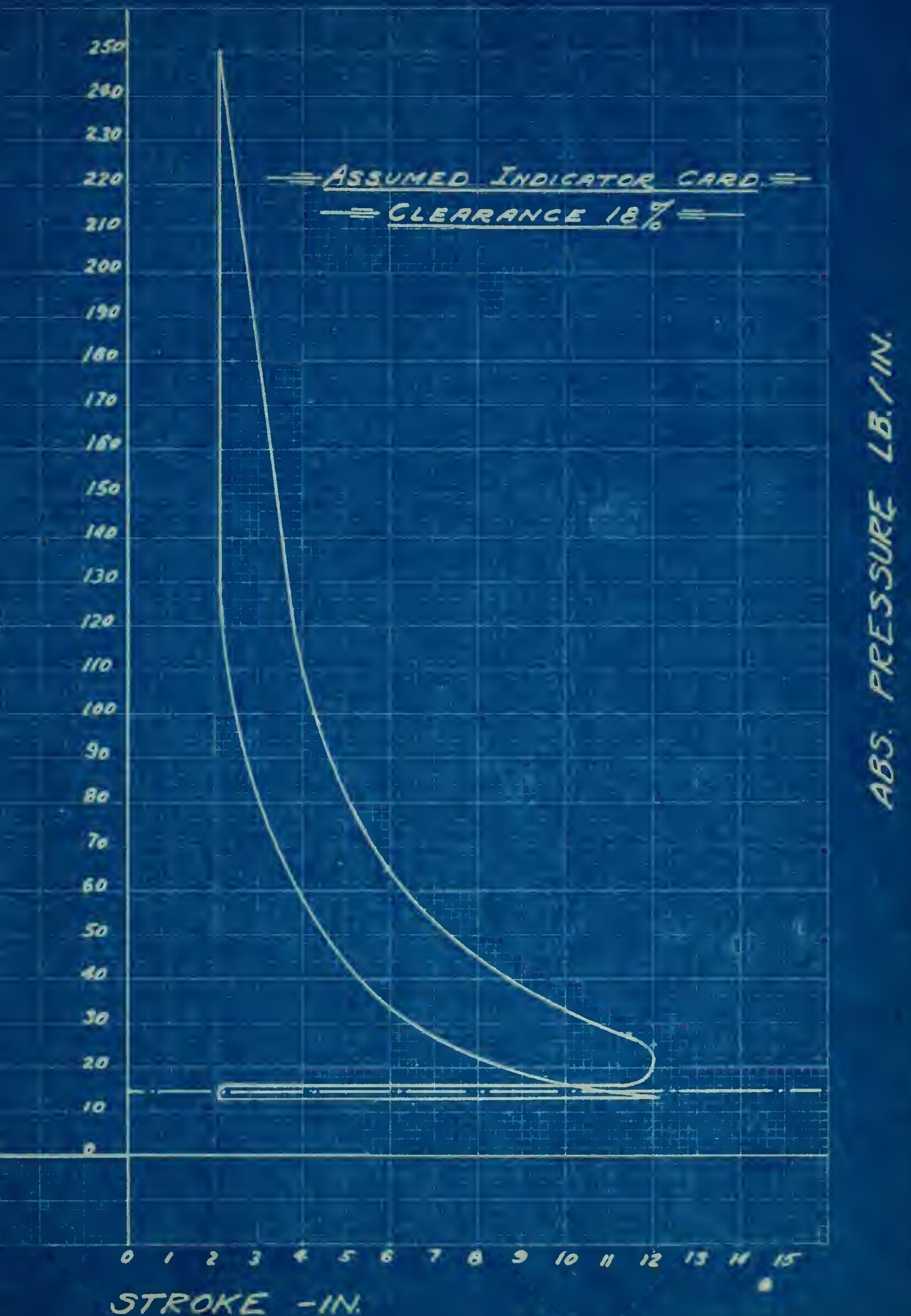
Expansion Line --- $pv^{1.3} = C$.

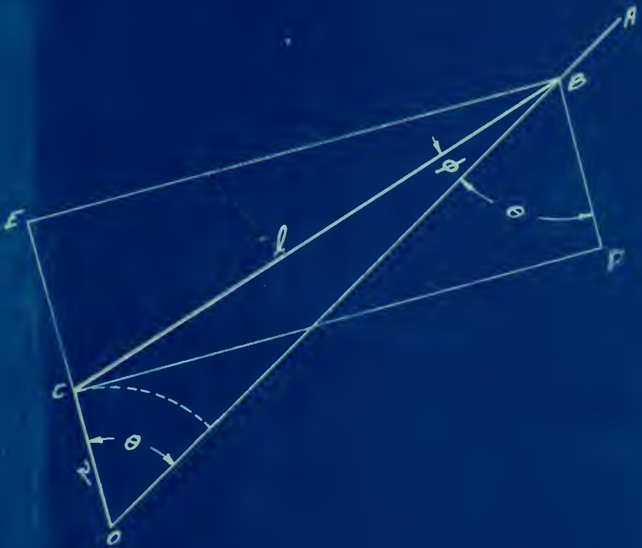
Explosion Pressure --- 250 lbs. / sq. in.

Exhaust Line --- 1½lbs. above atmospheric.

, Having constructed the card it was next necessary to develop it. That is, replot it on a set of coordinates where the abcissas ran from 0° to 720°, covering the entire cycle. This then, gives as indicated the pressure on the piston during any portion of the cycle.

If we should now combine this pressure curve with the reciprocating inertia force curve (which was calculated in detail), we would then


ASSUMED INDICATOR CARD
CLEARANCE 18%
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
STROKE -IN.
ABS. PRESSURE LB./IN.


A
B
E
φ
θ
l
D
C
θ
r
O

obtain the net force on the piston assembly, delivering the effort to the crank shaft. It is then necessary to obtain a mathematical expression for the value of this inertia force for each position in the crank shaft.

....

Referring to the figure, the crank OC of length r feet has moved an angular distance θ from dead center. At the same time, the connecting rod BC of length l feet, has moved through the angle ϕ.- Then since $l \sin \phi = r \sin \theta$, it is seen that

$$\sin \phi = \frac{r}{l} \sin \theta \text{ and}$$

$$\cos \phi = \left(1 - \frac{r^2}{l^2} \sin^2 \theta\right)^{\frac{1}{2}}.$$

While the crank and connecting rod have moved, the piston has also moved from A to B through the distance $S = AO - BO$

$$AO = r + l$$

$$BO = r \cos \theta - l \cos \phi$$

$$(1) \therefore S = r + l - r \cos \theta - l\left(1-\frac{r^2}{l^2} \sin^2\theta\right)^{\frac{1}{2}}$$

CONSTRUCTION OF 10 H. P. GAS ENGINE.

The angle θ is supposed to increase at the uniform rate of w rad. per second, which is expressed in the notation of the calculus as

$$\frac{d\theta}{dt} = w \text{ and } \frac{d^2\theta}{dt^2} = 0.$$

Then the velocity of the piston is

$$\frac{ds}{dt} = \frac{ds}{d\theta} \cdot \frac{d\theta}{dt} = \frac{ds}{d\theta} \cdot w.$$

$$= wr \left\{ \sin\theta - \frac{\frac{r}{l} \sin\theta \cos\theta}{\left\{1 - \frac{r^2}{l^2} \sin^2\theta\right\}^{\frac{1}{2}}} \right\}$$

Taking the second derivative, we get

$$\frac{d^2s}{dt^2} = w^2 r \left\{ \cos\theta - \frac{\frac{r}{l} \cos 2\theta}{\left\{1 - \frac{r^2}{l^2} \sin^2\theta\right\}^{\frac{1}{2}}} + \frac{\frac{r^3}{l^3} \sin^2\theta \cos^2\theta}{\left\{1 - \frac{r^2}{l^2} \sin^2\theta\right\}^{3/2}} \right\}$$

It is obvious that this does not differ much from the usual approximation,

$$\frac{d^2s}{dt^2} = w^2 r \left(\cos\theta - \frac{r}{l} \cos 2\theta \right)$$

If $M = \frac{\text{Reciprocating weight in lbs.}}{32.2}$

and $w = \frac{2\pi \times (\text{R.P.M.})}{60}$

and "r" =length of crank of feet

then Mw^2r multiplied by the coefficient within the brackets of equation 4 is the inertia force opposing the downward motion of the piston at any point. The algebraic sum of these inertia fordes at all the cranks of any engine, is the force causing radial vibration, which in a horizontal engine is entirely horizontal.

In the engine under discussion, the ratio of crank to connecting rod is very nearly 4. The following table gives the values of the coefficients of Mw^2r.

θ	Coeff.	θ	Coeff.
0	1.25	100	-.415
10	1.22	110	-.537
20	1.13	120	-.624
30	.995	130	-.683
40	.813	140	-.718
50	.602	150	-.737
60	.375	160	-.745
70	.146	170	-.749
80	-.06824	180	-.750

CONSTRUCTION OF 10 H. P. GAS ENGINE.

Weight of reciprocating parts = 46 lbs.

Mass = 46/32.2 = 1.43

Combining the thrust on the piston with the corresponding inertia of the reciprocating parts affecting it, we get the net force transmitted to the crank pin for producing torque.

Referring to the figure, if a force P acts in a downward direction, the thrust along the rod BC will be $\frac{P}{\cos \phi}$; and this can be resolved into the radio component CE and the tangential component CD acting on the crank pin at C, in a direction perpendicular to the crank CO, and producing the torque r x CD.

The angle OBD is equal to the angle θ ; and CBD $= \theta - \phi$ and therefore

CD $= \frac{P \sin (\theta - \phi)}{\cos \phi}$, and torque due to force

"P" is

Torque $= \frac{rP \sin (\theta - \phi)}{\cos \phi}$ which is also

an expression for the torque due to inertia only, as one is the reaction of the other.

CHAPTER SIX

Uses and Limitations of the New Engine.

An Analysis of its Probable Performance.

The engine was designed and intended to be used for experimental purposes in the gas engine laboratory at the Armour Institute of Technology. All possible variations encountered in the different designs of practice, were composited as much as possible in the design of this engine; and so the results obtainable in its performance are of considerable benefit.

The engine is of the slow speed heavy duty type used for driving farm machinery and the like. The conditions under which this engine would operate are such, as would make it necessary to have as few adjustments as possible; and simplicity must be the keynote in its design.

For localities in which natural gas and other gaseous fuels are rather plentiful, the engine is built so as to use these fuels with the highest efficiency possible with this size and type

of engine. The experimental work carried on with mixing valves applied, would assist considerably in the determination of compression, ignition, and valve timing, and also ratio of mixture. Such engines have been used constantly with numerous gases such as natural manufactured and coal gas.

Where gases cannot be obtained economically, a gasoline or kerosine carburetor can be fitted and used with one or the other fuel respectively. The major part of the work with this engine has been carried out with a gasoline carburetor fitted, and so the data obtained would assist more along an engine so equipped. When operated on kerosine, the low degree of volatility of this fuel should be taken into consideration. In this connection it would be necessary to preheat the fuel after atomization. This can be accomplished by employing the exhaust gases for inlet manifold preheating in some way.

It is known that engines operating, on kerosine, are very difficult in starting, and so some engines are fitted with double carburetors, allowing gasoline to be used for starting only, and then using the kerosine supply for continuous operation.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

The engine was designed to deliver ten horsepower at the brake, at a speed of 250 R.P.M., using gasoline as a fuel. Allowing for an assumed percentage of the power consumed in driving the engine itself, the total indicated horsepower produced is 11.5.

An indicator card was laid out under assumed conditions, which were thought at the time to conform quite closely to the characteristics expected of this engine. This card is shown in the text of the chapter on shaking forces.

Using the formula for I. H. P.,

$$H.\ P. = \frac{P.L.A.N.E}{33,000}$$

where P = mean effective pressure in lb. 1 sq. in.,

L = length of stroke in feet,

A = piston area in sq. in.,

N = number of power strokes per minute,

and E = mechanical efficiency of engine,

we solve for the "P" required to obtain the 10 brake horse power when a mechanical efficiency of 80% is assumed.

We get

$$P = \frac{33000 \times H.P.}{LANE} = \frac{33000 \times 10}{.83 \times 38.5 \times 62.5 \times .8} = 206\# / \text{Sq. In.}$$

which is the mean effective pressure according to calculations.

Integrating the indicator card, and deducting the negative loop, we obtain 192# / sq. in. as the mean effective pressure.

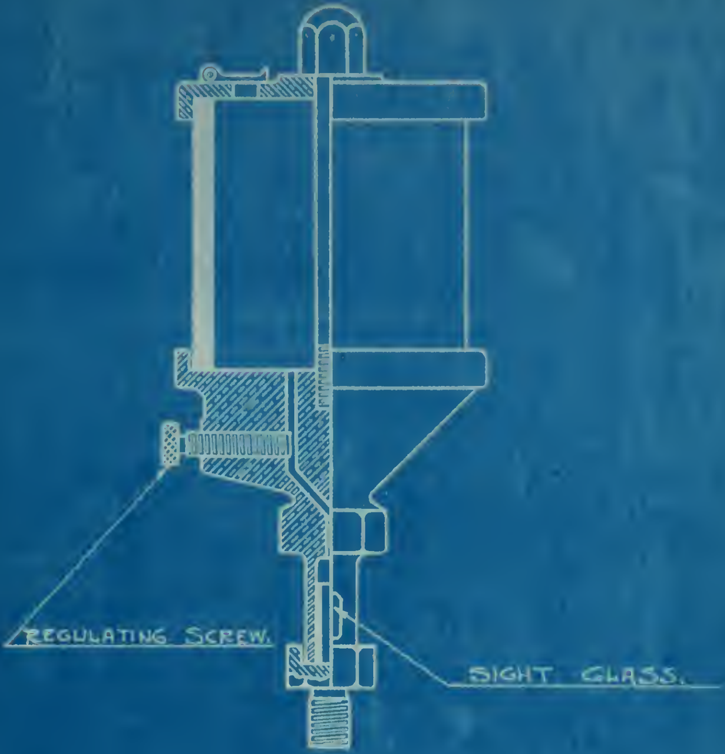
The card drawn is a full load card, drawn up under ideal conditions. It can then be seen that if the mechanical efficiency as assumed, is approximately correct, the engine will not deliver its rated output. The percent of reduced output is 7.3%, everything else remaining as assumed.

CHAPTER SEVEN

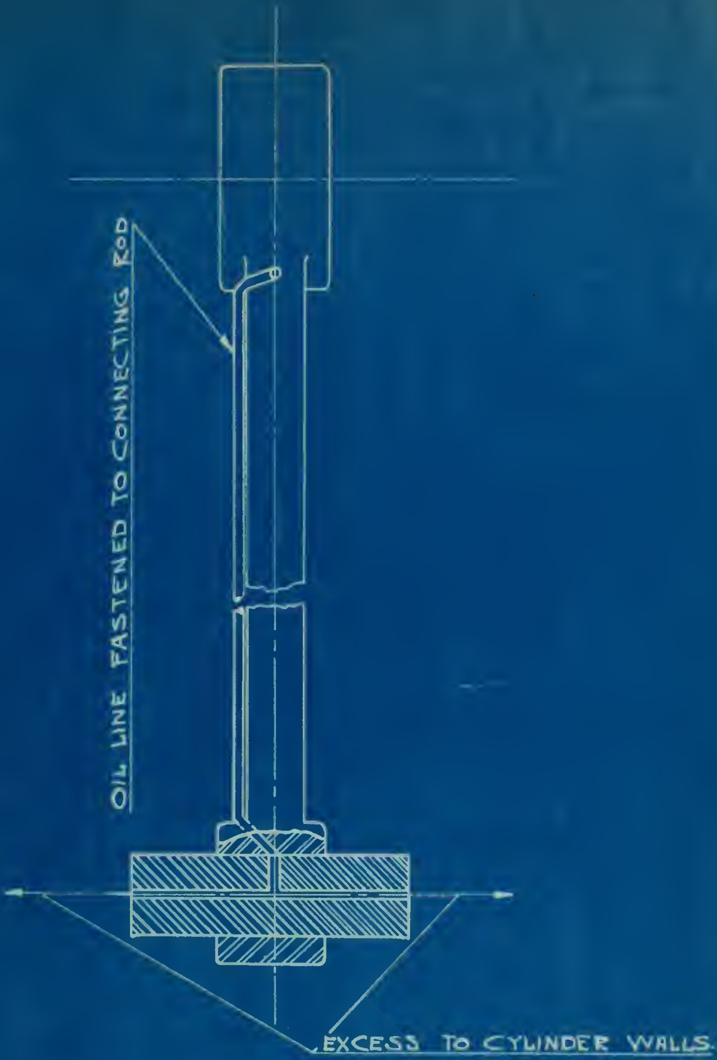
Lubrication, Cooling, Carburetion and Ignition.

As suggested in the original work, a pressure system of lubrication was considered, and found not adaptable to this type of engine; because of slow speed and difficulty of providing pressure leads to the various moving parts. Also a pressure pump would be necessary. A sight-feed oil cup system of lubrication was finally decided upon, which involved the use of separate oil cups on each bearing (main and connecting rod), and a tube carried by the rod itself, running into the wrist pin bushing. From there the oil is carried through the hollow wrist pin to the cylinder walls. This tube is fed from the large end of the connecting rod by an oil cup, located near the cup feeding the large end of the rod. This provides then, a simple and positive type of sight feed lubrication, which embodies no moving parts and is very easy to maintain.

The accompanying sketch shows a view of the oil cup and of the connecting rod and wrist pin assembly, showing the details of the oil ducts.



OIL CUP USED WITH
REGULATED SIGHT FEED.


OIL LINE FASTENED TO CONNECTING ROD
EXCESS TO CYLINDER WALLS.

METHOD OF LUBRICATING
WRIST PIN AND CYLINDER WALL.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

No change in the cooling was made as far as the original design is concerned. Inasmuch as this engine is of the stationary type, and since city water pressure is available, the problem of cooling becomes a very simple one and reduces down to the regulation of the flow of water to the jackets as controlled by a hand valve in order to keep the temperature within normal operating limits.

Cold water enters the cylinder at city water pressure or any fraction thereof, as controlled by hand valve. There is a provision at this point for the insertion of a thermometer. It then circulates through the jackets and leaves at a point in the upper part of the cylinder head, from where it is discharged to waste. There is a provision at this point also for the use of a thermometer.

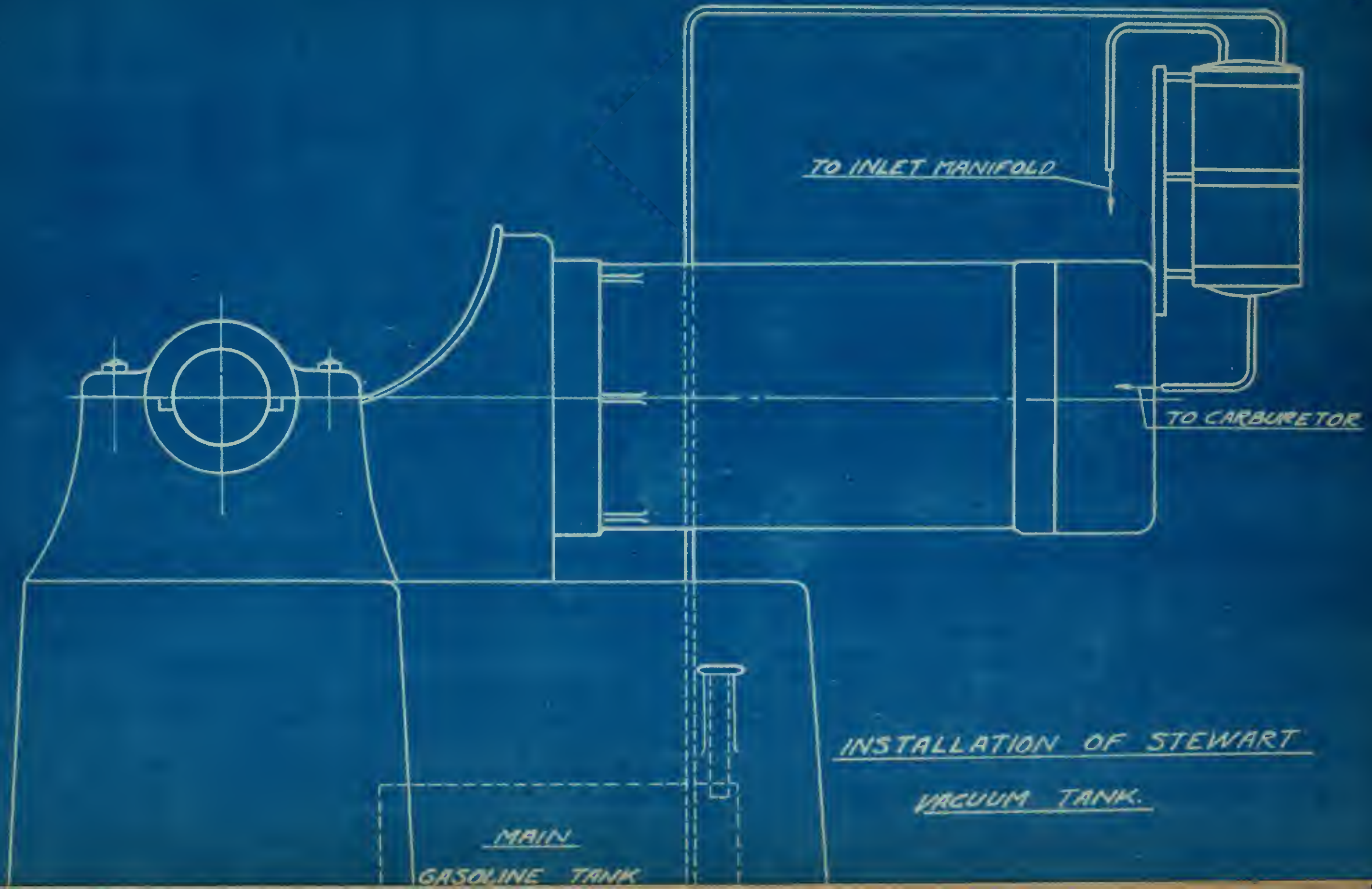
At the top of the cylinder just above the inlet, there is a tapped opening fitted with a pet-cock. Should any pocket of air lodge itself in the upper part of the cylinder and prevent the free circulation of the cooling water, this cock can be opened to break up the pocket and release the air.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

No definite provisions have been made as to the means of handling carburetion. This is due to the fact that it is intended to use both liquid and gaseous fuels for purposes of experimentation. Where gaseous fuels are used, it is advisable to use a mixing valve similar to that in use on the Westinghouse three cylinder engine in the gasoline laboratory. Inasmuch as a governor mechanism is contemplated in conjunction with speed control, a mixing valve design would take care of this requirement.

For initial experiment, however, it is intended to use gasoline as a fuel, and so a carburetor is necessary. This can be of the standard automobile type with a 1½" manifold connection. Since the intake port has a diameter considerably greater than the carburetor connection, it will be necessary to use a reducing manifold.

The sketch shows the installation of a Stewart vacuum tank to be used for feeding gasoline to the carburetor by means of the inlet manifold suction.

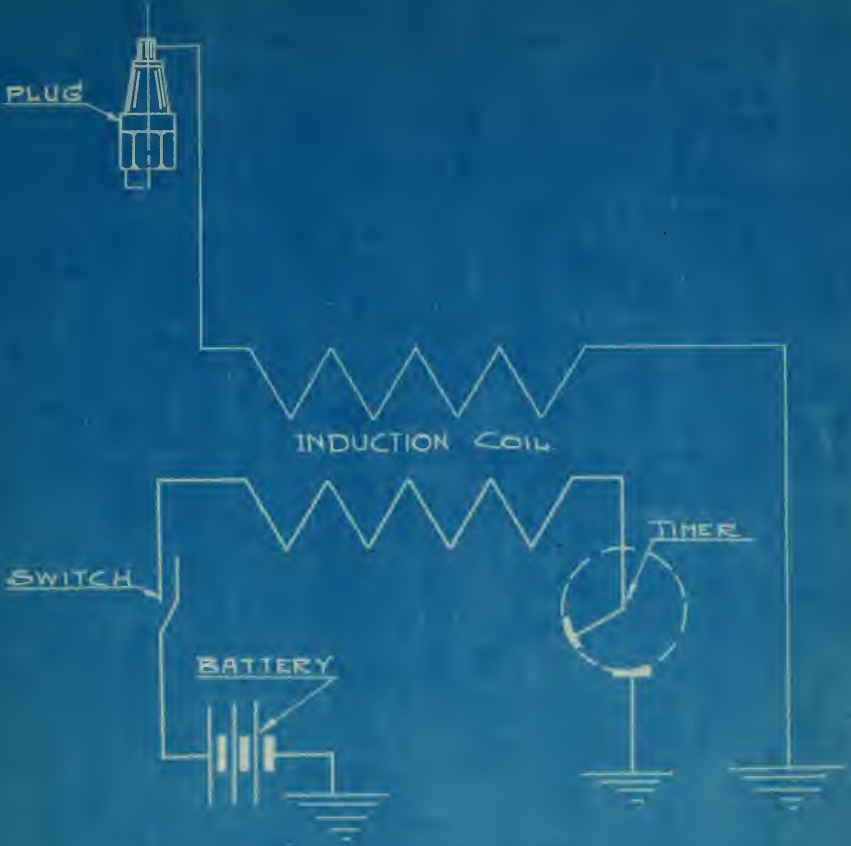


INSTALLATION OF STEWART VACUUM TANK.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

In the matter of ignition, it is intended that two separate systems be installed on the engine, and each one switched in when desired.

One type will be the battery system of ignition in which current as furnished by a storage battery, is sent through a trembler coil primary and thence returning through the timer to the ground. When the timer makes contact with the grounded roller, which operation occurs at the proper time for ignition, the primary coild is energized and induces a high tension current in the secondary winding which is then in series with the spark plug. The result is a vibrating spark which continues as long as the timer remains in contact with the ground, because of the trembler mechanism on the induction coil. If the trembler were omitted, then only a single spark would be obtained. A switch is placed in the low tension circuit so that the current through the coil flows only when it is desired to run the engine.



BATTERY IGNITION
WIRING DIAGRAM.

The other type of ignition is the magneto. A high tension magneto similar to those used on motorcycle will be installed. This combines the breaker mechanism, source of current, and induction coil in one compact unit; the difference between this and the battery type being in the kind of current generated. The magneto furnishes an alternating current while the battery system delivers direct current.

The object of the two systems is to note the difference if any, between magneto and battery ignition, and also the advantages and disadvantages of both. In operation the engine will be started by using the battery system and then switched over to the magneto side for running.

The wiring diagrams show, in a conventional manner, the layout of both systems and the relation between these units and the different parts of the engine..

CHAPTER EIGHT

Conclusion and Field for Further Work Along Lines of this Investigation.

The work of this thesis, as far as it has been carried on by the writer, is only a small fraction of the work necessary to arrive at any definite results from such an investigation. It will then be necessary for others to follow up and make more complete the work already accomplished.

First of all, at the present time, the engine is not yet complete, and it is necessary that the men working along these lines in the future, complete and assemble the engine according to the present design.

Testing the engine should next be undertaken, and care should be given the valve timing and spark advance with reference to results obtained in operation. Various sets of cams can be designed to effect different results, and the layout is such that cam changes can be very easily brought about.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

After the experiments along valve and ignition timing have been carried out to some extent, attention should be paid to the matter of compression and its effect on engine performance when varied. In connection with this work, it will be necessary to design and set up a prony brake for measuring the power output.

Carburetion will no doubt present many problems to the investigators, which cannot be outlined here. The compression should be closely studied in this connection.

When all the preliminary experiments have been carried out, it will be advisable to draw up a standard log form for such determinations as thermo efficiency, B. H. P. etc.

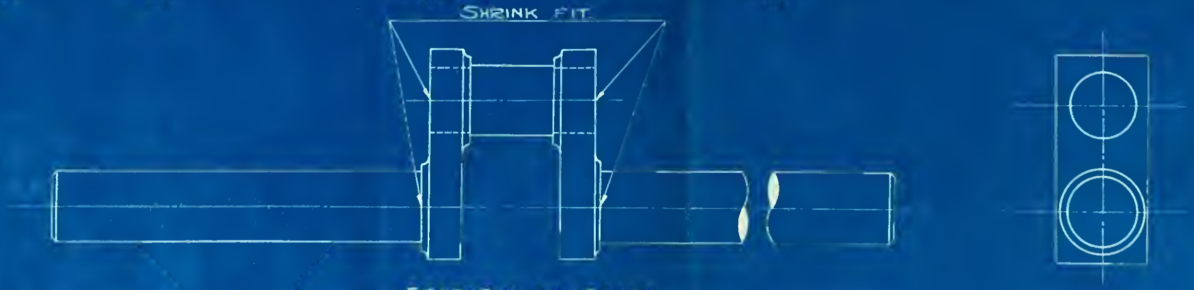
In the matter of redesign, many things will need attention. The lubrication system may not function properly; and, as a result, it may be necessary to provide changes here during the experimental work on the engine.

CONSTRUCTION OF 10 H. P. GAS ENGINE.

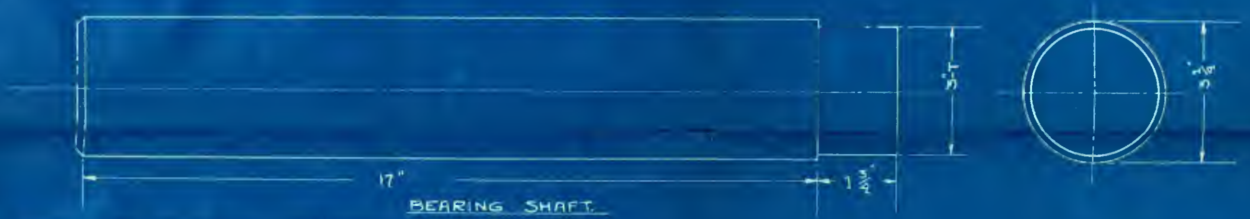
The valve gear will need a probable change here and there, especially to make the design more compact and efficient. This can only be accomplished by further study and experiment.

The bearings will require further study, and a determination of the most suitable type for each location must be made.

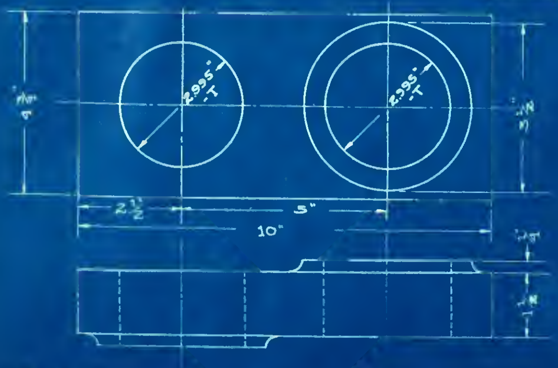
A governor mechanism should be designed and studied. Inasmuch as this is a constant speed variable load engine, a governor is essential and the design of the proper type will be involved here.



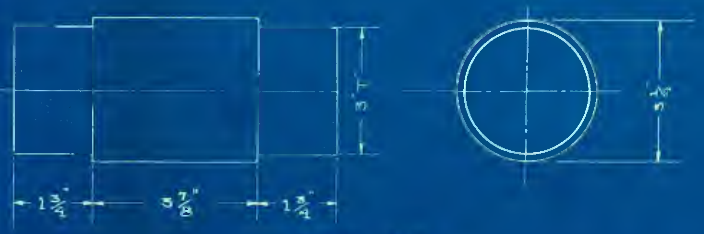
ASSEMBLY OF SHAFT.



BEARING SHAFT.



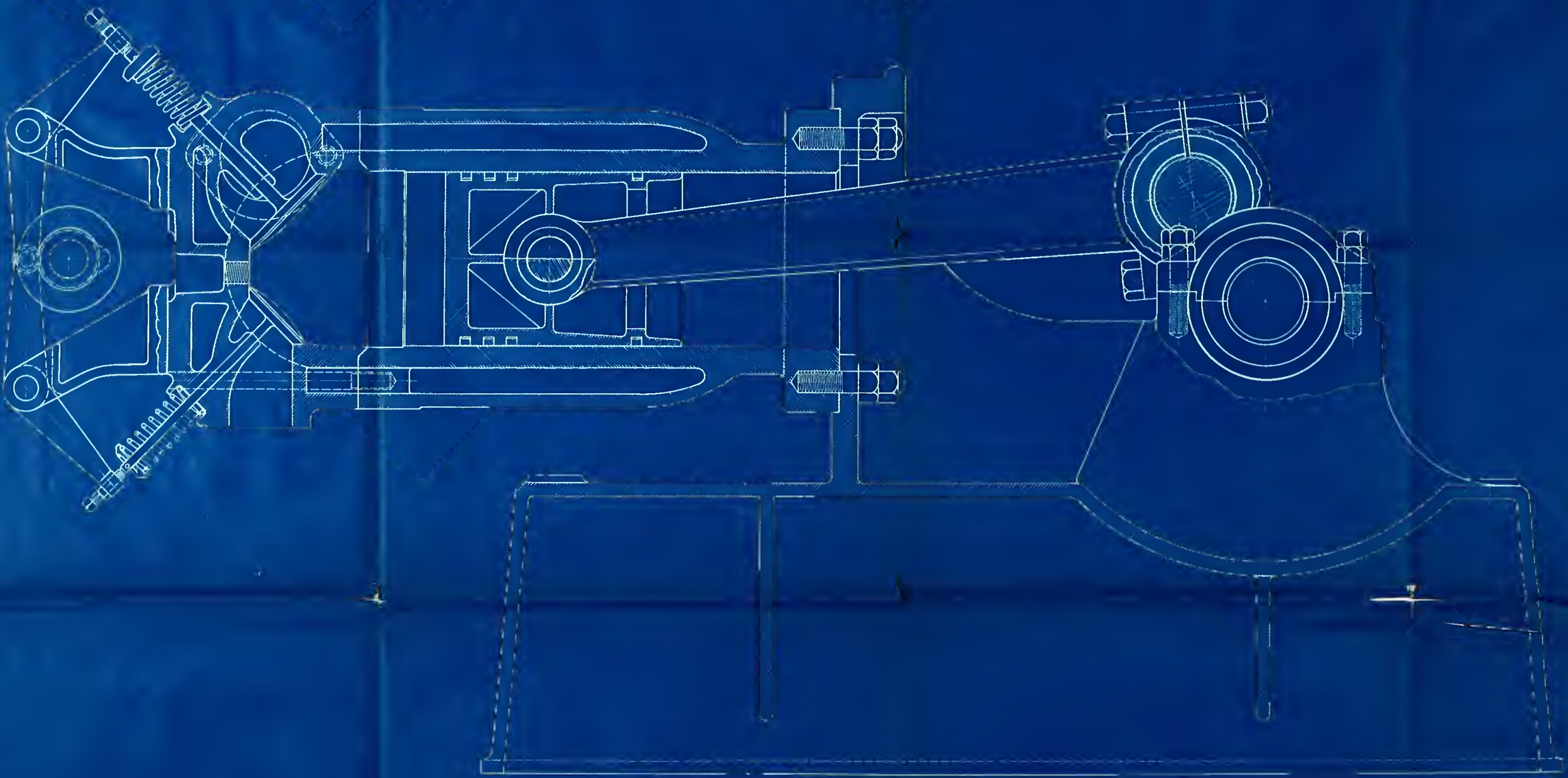
CRANK CHEEK



CRANK PIN.

NOTE: DIMENSIONS MARKED "T" HAVE
A TOLERANCE OF + OR - .001"

CRANK SHAFT FOR
10 HP GAS ENGINE
DRAWN BY GEO. HENRY
CHECKED BY J. MITNICK
APRIL 23, 1920 THESIS-M.E
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO ILL



ASSEMBLY OF A

10 H.P. GAS ENGINE

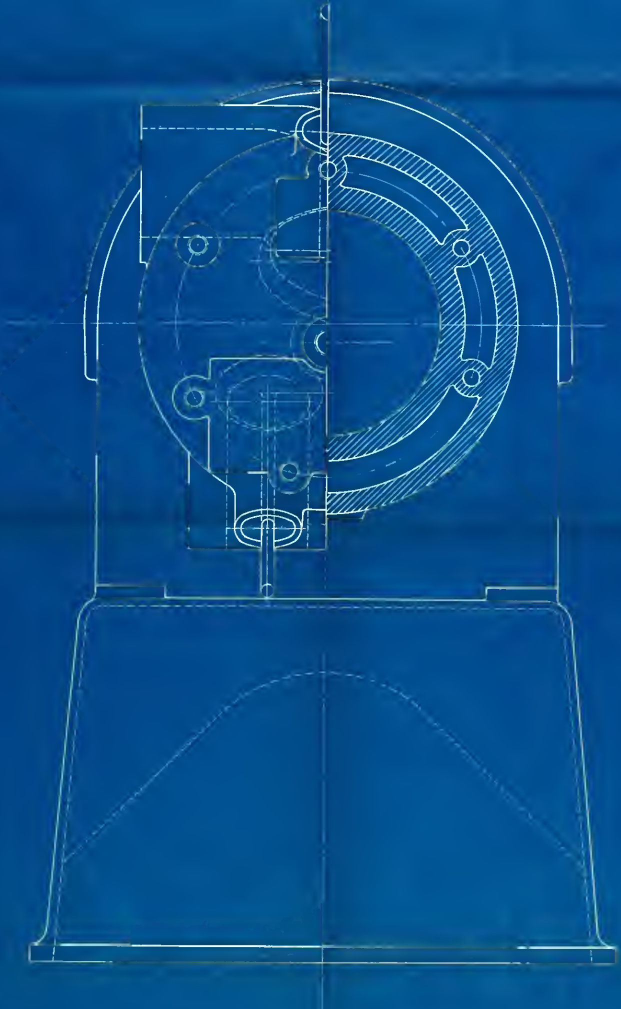
DRAWN BY M. D. Gottlieb

CHECKED BY [illegible]

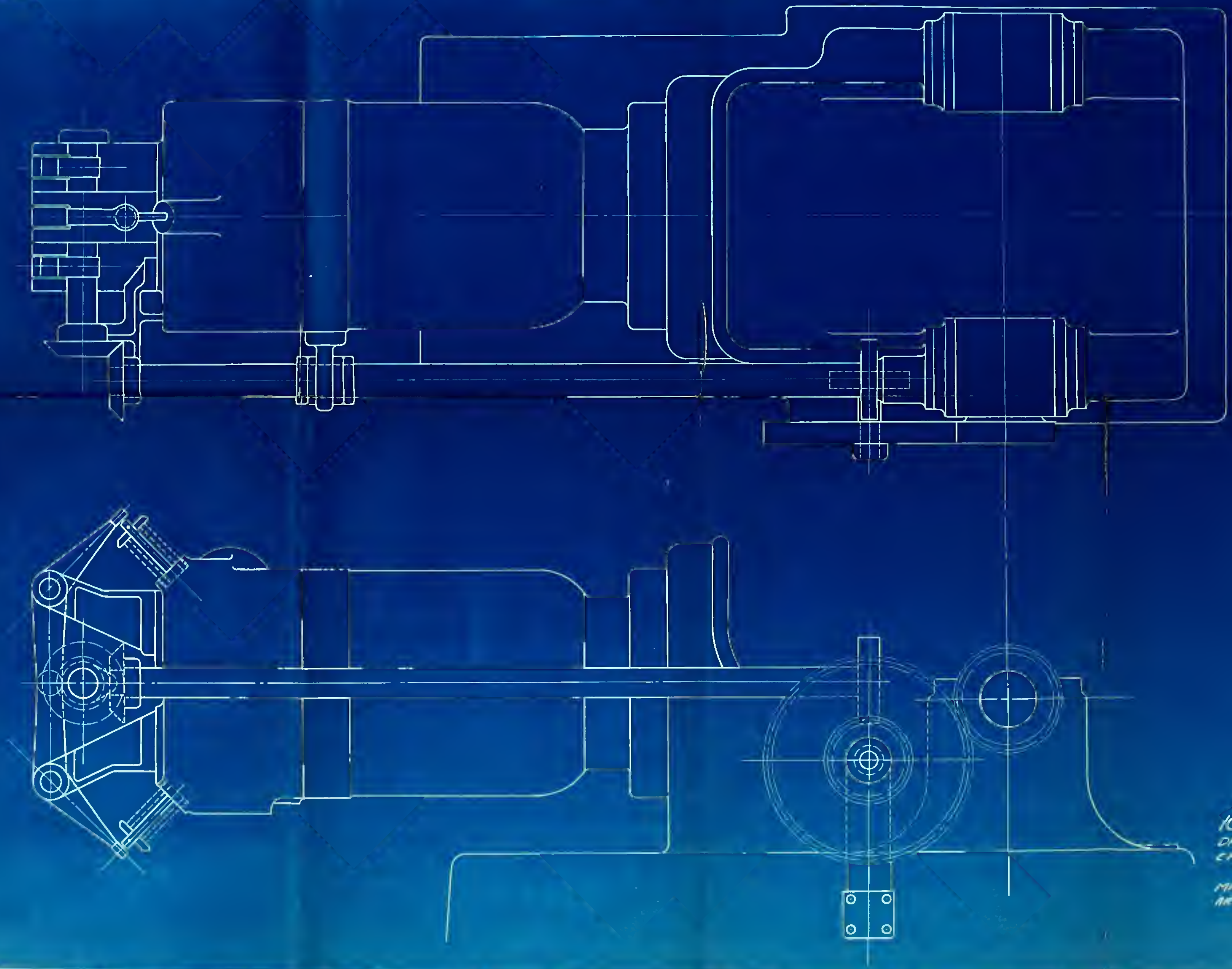
APRIL 30-1920. THESIS 1920

ARMOUR INSTITUTE OF TECHNOLOGY

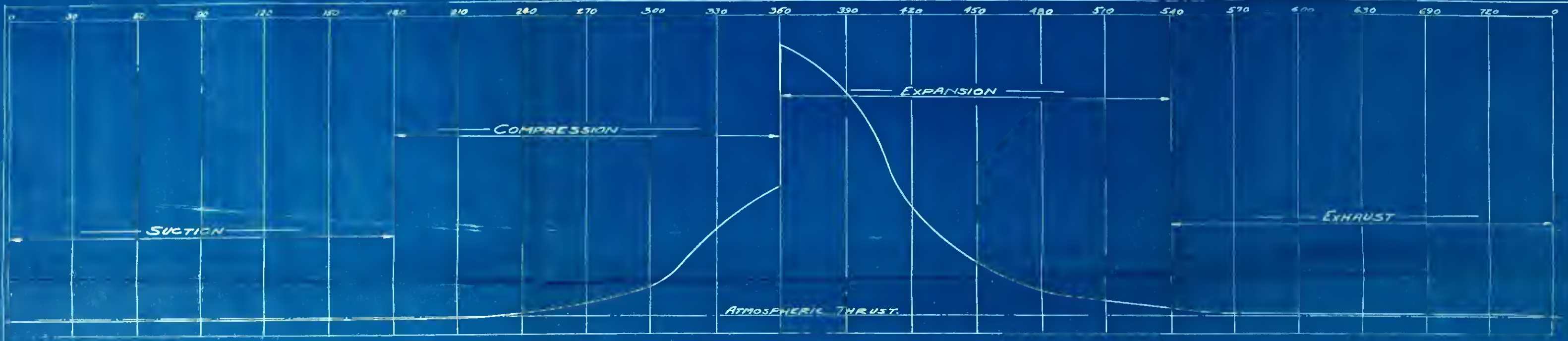
CHICAGO, ILL.



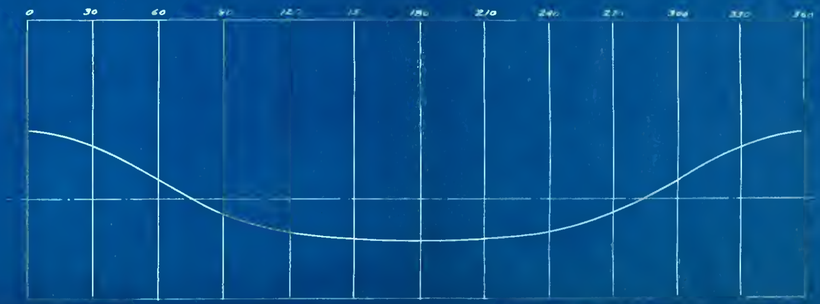
END ELEVATION
10 H.P. GAS ENGINE
DRAWN BY G. Henry
CHECKED BY J. Mitnick
MAY 12, 1920 THESIS 1920
SCALE 6" = 1'
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.



VALVE GEAR LAYOUT
10 HP GAS ENGINE
DRAWN BY J. Mitnick
CHECKED BY G. Henry.
SCALE 4" = 1'
MAY 12, 1920 THESIS M.E.
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO ILL.

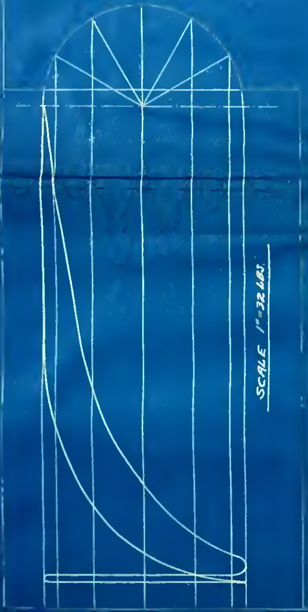


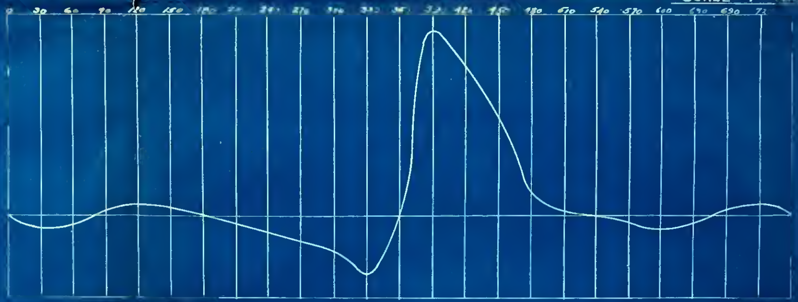
PRESSURE CURVE - SCALE 1" = 2000 LBS.



UNBALANCED HORIZONTAL INERTIA FORCES

SCALE 1" = [illegible]00 LBS.

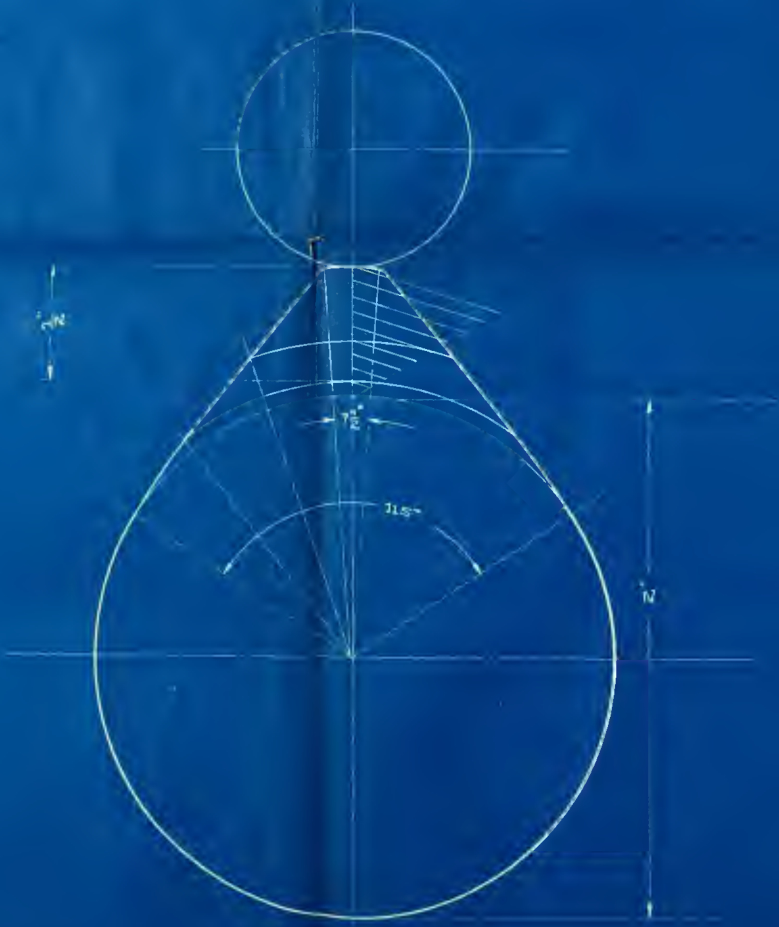


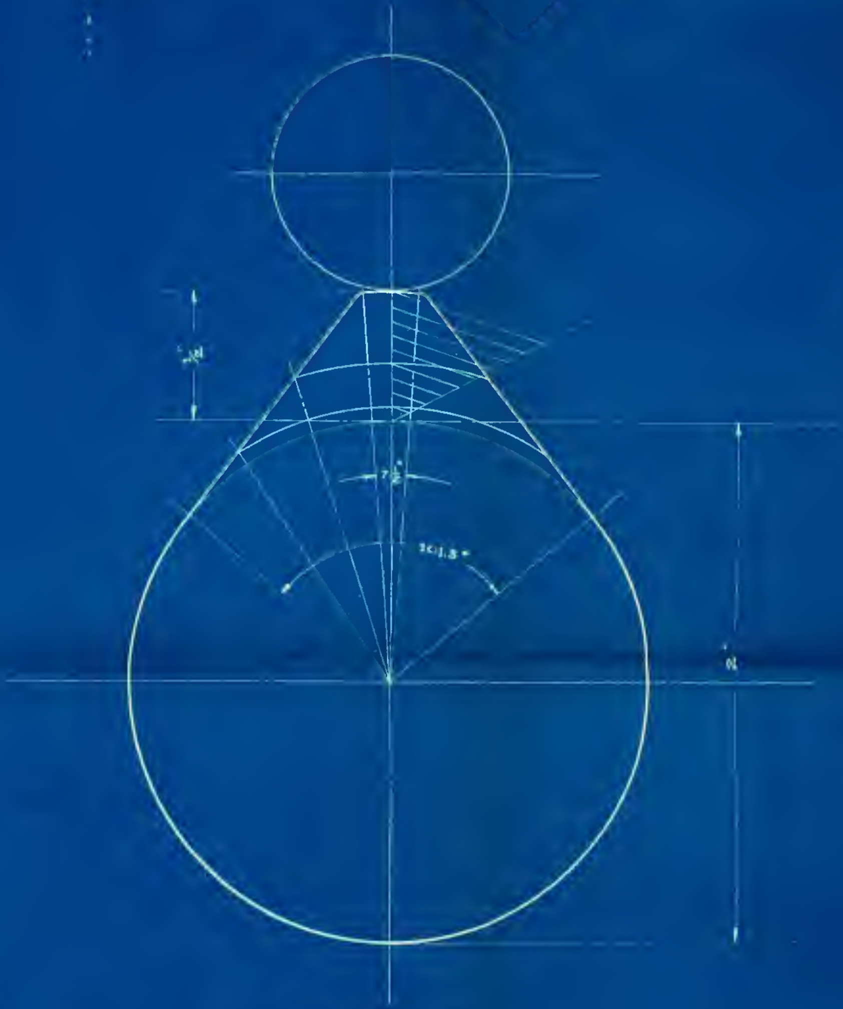


TURNING EFFORT CURVE SCALE 1" = 500 FT-LBS.

SHAKING FORCE LAYOUT FOR
10 H.P. GAS ENGINE
DRAWN BY J. MITNICK.
CHECKED BY G. HENRY.
MAY 10, 1920 THESIS M.E.
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO ILL.

EXHAUST CAM.	
RISE	½ IN.
ACTION	115.0°
DWELL	7.5°
UNIFORM	ACC RISE
"	" FALL.





INLET CAM.	
RISE	½ IN.
ACTION	101.5°
DWELL	7.5°
UNIFORM	ACC. RISE
"	" FALL

CAM LAYOUT

10 HP. GAS ENGINE

DRAWN BY
CHECKED BY
MAY 11, 1920 SCALE 3" = 1'
THESIS - M.E
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL